M2 INCREMENTAL UNDERWATER MAPPING IN 6DOF WITH STEREO TRACKING

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Abstract
This work presents preliminary results on the implementation and application of a delayed state Kalman filter for the trajectory estimation of an Autonomous Underwater Vehicles. Novel aspects include the use of high resolution stereo still camera as the main navigation sensor, and the creation of a sparse 3D point cloud representation of the environment concurrently with the navigation.

Keywords Stereo-tracking SLAM underwater 3D-reconstruction Kalman-Filter

INTRODUCTION

One of the crucial aspects of a mission performed with Unmanned Underwater Vehicles (UUV) is their localisation within the surveying area. Whereas gyroscopes and depth gauges provide drift-free measurements of attitude and depth directly, the absolute measurements of longitude and latitude can only be obtained by complex acoustic positioning systems such as Long, Short or Ultra-Short Baseline (LBL, SBL, USBL) transponder networks, with high associated mission costs. Dead reckoning (DR) techniques can be used with less expensive sensors to estimate the motion of the vehicle with respect to the previous position. The main drawback is that absolute positioning from incremental measurements is affected by drift, due to error accumulation.

The most common DR sensor in underwater navigation is the Doppler Velocity Logger (DVL) but the possibilities of visual techniques, widely used for purpose of Simultaneous Localisation and Mapping (SLAM) within terrestrial application, are finding growing interest amongst researchers for underwater environments, also because the possibility of loop closure allows to significantly reduce the final error and uncertainty [1]. Furthermore, optical data provides a huge amount of information useful for different aims and fields such as classification of marine organisms, 2D and 3D representation of seabed [2, 3].

The present paper shows how images taken with a calibrated stereo-rig can be combined with data from different sensors in an Augmented State Kalman Filter (ASKF), to achieve SLAM with loop closure capability. A central objective is to obtain, at the same time, both the trajectory of the vehicle and a sparse 3D reconstruction of the surveyed scene.

STEREO-TRACKING

The acquisition of optical data in AUVs is often restricted to interval shooting of still images because of the higher power consumption required by continuous video acquisition and illumination. The acquired images have to present a satisfying overlapping in order to ensure the full path estimation.

The stereo-pairs have to be acquired by a pre-calibrated stereo imaging system. After image enhancement, rectification and resizing, scale invariant descriptors (SURF or SIFT) are extracted from each image and matched within the stereo-pair and within consecutive frames, if overlapping. Knowing the relative left-right pose of cameras, each stereo pair provides a fixed-scale cloud of 3D points by stereo triangulation. Hence, at each iteration, the same 3D structure of points is seen from two different poses of the stereo-rig and their association is known by the image matches. The two sets of 3D points are registered using RANSAC to estimate the relative translation and rotation of the robot between time steps.

The robustness of the resulting 3D cloud and pose estimation is ensured by the different filtering processes performed. In fact, all the features are visible in four images and filtered according to epipolar geometry and the whole 3D structure have to be coherent with the motion estimation; furthermore, the pose and the structure estimations are refined with a local iterative process of reprojection error minimisation, performed by bundle adjustment, which takes in account the sparseness of the data. We use a covariance propagation method to obtain the uncertainty of the relative measurement for both camera pose and points tracked. The estimated pose and its covariance are then used as observation input for the ASKF, along with the AUV navigation data.

TRAJECTORY AND SCENE ESTIMATION

The Extended Kalman Filter (EKF) is a standard tool to fuse data coming from different sensors, and to estimate the motion. The Augmented-State EKF is a particular implementation that allows to store the whole set of previous poses and to add constraints related to loop closure events. Our state uses a 6 degrees of freedom (DOF) representation of the vehicle pose, consisting of three translation components and three rotation angles.

In addition to the 6DOF incremental pose representation coming from optical data, other navigation data is incorporated. In particular, the absolute angular pose is measured by fibre-optic gyroscopes, the depth by a pressure gauge, and velocities by a DVL. In the presented test case, the filter state is augmented each time a new image pair is available. If the number of matched features in the subsequent pairs is lower than a minimum threshold, the filter only considers the observations from the other sensors.

After estimating the current pose, candidates for loop closure are searched for. Candidates are chosen between all previous positions that are closer than a certain distance to the current one, considering only the 2D position on the survey plane. When a crossing path happens, the implemented algorithm also correct the 3D structure and the covariance associated to each point of it.

RESULTS

The presented work has been tested with a real dataset acquired during a survey performed on the XVII century shipwreck of La Lune, using the Girona 500 AUV, which is a high-reconfigurable, compact-size AUV developed by the University of Girona (Fig.). Our stereo imaging system consists of two Canon EOS 5D Mark II cameras electronically synchronised, installed in the free payload area of the AUV together with the illumination system. They were in a down-looking configuration, pre-calibrated and they shot at 0.5Hz. The AUV surveyed at a nominal altitude of 3.68 m and at a nominal forward speed of 0.5 m/s. The total bottom time was 103 minutes, split into two surveys, during which 2757 stereo images were acquired.

For testing purposes, a subset of 310 stereo images has been extracted and processed following the pipeline described above. The obtained results have been compared with the trajectory estimated from mosaic reconstruction. The estimated trajectory of the left camera is visible in Fig. 2. Blue frames show where a loop is closed, whereas red frames are subsequent non-overlapping images.

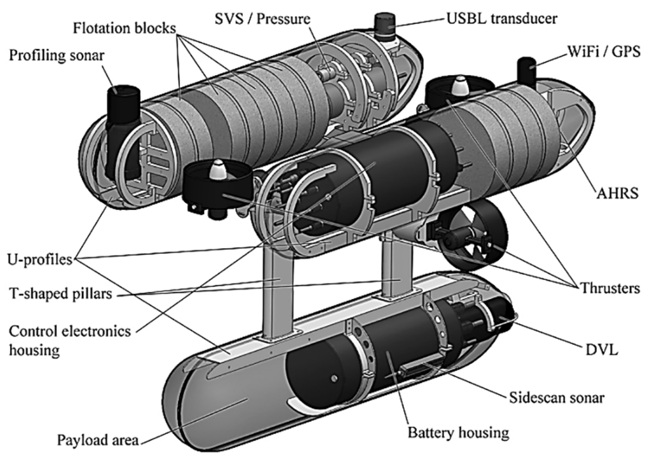

Fig. 1 Schema of the Girona 500 AUV, showing the location of principal components and payload area.

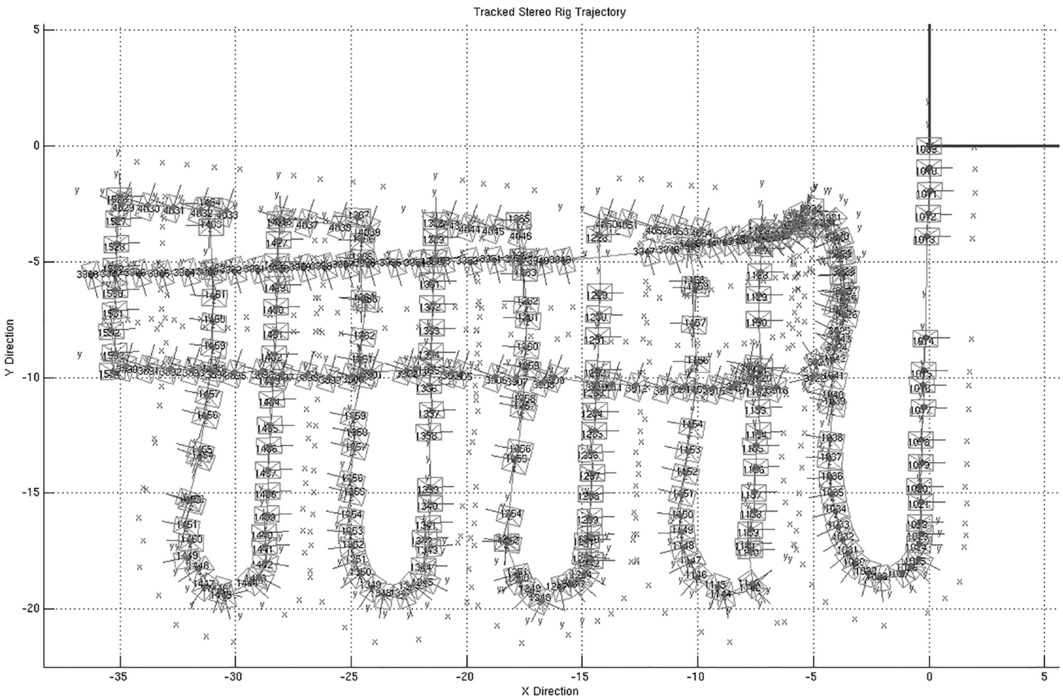

Fig. 2 Trajectory estimated for the left camera: blue frames represent loop closures; red frames are non-overlapping subsequent images.

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